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Wind energy in Egypt: Economic feasibility for Cairo

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ABSTRACT

Motivated by the rise of the electricity tariffs applied on industrial customer and the frequent electricity cut offs recently experienced in Egypt, this paper assesses the economic feasibility of installing a stand alone wind energy technology by an industrial customer who seeks to reduce his dependency on the national grid. For this purpose, the wind energy potential at the wind regime of Cairo was chosen to be assessed using half an hour wind speed data for a full one-year period (2009). The Weibull parameters of the wind speed distribution function were estimated by employing the maximum likelihood approach. The estimation revealed that Cairo has poor wind resources. Despite the poor resources, the financial analysis has shown that under certain parameters the wind project can prove to be financially viable. Thus harnessing wind energy through stand alone systems can help in meeting the industries electric power needs.

Contents

1. Introduction

The future of energy in Egypt is challenging. The local demand for energy and electricity is rapidly growing at the same time where the two major energy sources of the country, namely oil and natural gas, are in a precarious situation. As in one side, the Egyptian oil reserves are depleting and there are high and justifiable expectations that in the coming few years Egypt – traditionally a net exporter – will be a net oil importer country. And with this depleting oil reserves situation, natural gas on the other side has to balance between two equally important roles, the role of the main energy source feeding growing local needs and the role of the main exported fuel that guarantees for Egypt an indispensable flow of hard currency. This double role can in fact cause a faster depletion of the rich natural gas reserves that Egypt currently enjoys [1–3].

Acknowledging this critical energy situation and in order to face this challenge, the Supreme Council of Energy[1] has approved in 2008 a strategy to diversify the energy sources in the electricity sector and reduce the dependency on fossil fuel by considering

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[1] The Supreme Council of Energy is the highest policy making authority in the Egyptian Energy sector [2].

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a larger contribution from renewable energy sources [4]. Accordingly, the share of renewable energy in the electricity generation should reach 20% by the year 2020 excluding the share of the large hydropower plants. And the dominant role in this renewable strategy was assigned to wind energy that should by the year 2020 generate 12% of the electricity supply whereas it currently supplies only 1.8% [4,5]. And as recognized by the Egyptian government, this ambitious increase in the share of wind energy cannot be realized except with an active participation from the private sector. This is why an encouraging framework for the entry of the private sector in the wind energy market has been designed under the proposed new electricity law[2] [4]. Furthermore, the New and Renewable Energy Authority (NREA) is currently encouraging energy intensive industry to build wind energy projects in order to feed their own electricity demand. However no intensive industries have yet started its autoproduction of electricity from wind and all installed wind plants have been either demonstration projects or large scale projects initiated under the cooperation or sponsorship of international donors and with the NREA[3] as a local project developer [4].

In this paper, the decision to harness wind energy to autoproduce electricity will be assessed from the perspective of an industrial electricity customer. In fact, such a decision to autoproduce electricity in order to feed the industry operation may become soon a potential investment decision given the expected increase in electricity prices that the industrial customer will witness with the elimination of electricity subsides.[4] Therefore this empirical paper is addressing a particular research question which is: will the installment of a wind energy conversion system by an energy intensive customer be an economically feasible decision? And under which conditions will such an investment decision pay off?

In fact, a few numbers of studies were carried out on wind power and its applications in Egypt [6,7]. The wind energy potential at the Red Sea and the Mediterranean coast along with some interior parts of Egypt were analyzed in the study of Mayhoub and Azzam [8]. Ahmed and Abouzeid [9] have presented a study about utilizing wind energy in some remote areas to feed part of the need of some isolated communities. The studied areas were on the north coast, the red sea coast and the east of Oweniat. The Red Sea coast was again the scope of the work presented by Shata and Hanitsch [6] where an assessment of several regions on the red sea coast was conducted. In their study the researchers have estimated based on a technical and an economical assessment the cost of generating wind electricity in the studied regions and found it to be very competitive when compared to the other sources of electricity generation. With respect to the coast of the Mediterranean Sea, Shata and Hanitsch [10] have evaluated the energy potential along with the generation cost analysis of ten locations and found that three of the ten locations, namely, Marsaa Matrouh, Sidi Barani and Eldabaa were well suited for wind electricity generation given their favorable wind characteristics. The same authors have also identified the wind electric potential of the coastal city; Hurghada [7]. The most recent study conducted over an Egyptian site was the assessment of the city of Ras Benas situated on Red Sea coast and was presented by Shata [11].

The novel contribution of this paper is that it assesses the potential to generate electricity from the wind resources of the city of Cairo. In fact no previous study that the research knows of was conducted until now on this region and as it can be noticed from the discussion of the work carried over areas in Egypt, all the studies were exclusively concerned with the assessment of the wind potential either in coastal or desert remote areas whereas no single study was concerned with the power potential of wind inside or near by non coastal cities. The second element of novelty in this study is that it does not end where an answer about the power potential of the studied wind regime is reached but it follows the wind regime assessment with an economic feasibility study adopting a new perspective which is the perspective of an energy user aiming at reducing his electric bill via a self installment of a wind energy conversion system. And this is unlike all the studies carried over Egypt where the economic assessment were conducted either to assess the feasibility of large wind farms and bulk power generation (see the study in El-Sayed [12] conducted over Zafarana wind farm) or to estimate the production cost of wind generated electricity from the energy supplier perspective (see [7,11]).

Furthermore Cairo is a highly polluted city [13,14] surrounded with many industries and power stations such as that in Helwan and Shobra-Elkeima [15] so studying the possibility to supplement the conventional power plants with renewable source of energy poses itself as an important research topic given that a major source of harmful emissions that causes environmental pollution is caused by heat power stations [16].

This paper is organized as follows; in Section 2 the theoretical framework for the wind energy estimation is presented where the Weibull wind speed distribution function and the maximum likelihood technique used to estimate the Weibull parameter is exposed. The wind speed data used in this study is described in Section 3 and the results of the wind energy estimation as well as the feasibility analysis are given in Section 4. The conclusion of this study is presented in Section 5 of the paper.

2. Weibull as a distribution function for wind speed

The analysis of the wind regime at a prospective site represents a fundamental step before developing any wind energy project as the cost of generating energy from wind in a specific site is heavily dependent on the wind resources that this site enjoys [17,18]. In fact, the wind resources in a site are critically influenced by the wind speed (also called wind velocity) due to the existence of a cubic relationship between the wind speed and the wind power and consequently a small increase in wind speed can considerably increase the generated power. Accordingly, the average wind speed of the studied wind regime is a very important information in assessing the site's wind energy potential. But the average speed over a period can only give a preliminary idea about the wind energy potential and that idea must be completed with a description of the regime's wind speed distribution [19].

During the last 50 years, many distributions functions were suggested to describe the wind speed distribution among which was the Pearson, the Chi-Square, the Weibull, the Rayleigh and the Johnson functions. And among many non normal distributions used to represent wind speed – such as the log normal, the inverse Gaussian, the squares normal – the Weibull distribution is the most commonly used in the wind literature [20–22].

The Weibull distribution function has been initially applied in 1930s by the Swedish physicist W. Weibull in the field of material strength in cases of tension and fatigue. This distribution has proved to be closely matching the probability law of many natural phenomena among which is the wind speed. Actually, the wind energy literature considers the Weibull distribution as well

[2] This law has been under consideration since 2008 and was expected to be ratified by the parliament by the end of 2009 [40].

[3] The NREA: The New and Renewable Energy Authority was established in 1986 and is mandated by the Egyptian government to plan and implement renewable energy programs [4].

[4] According to the new electricity law, the electricity market will be liberalized in 2011 and subsidies will be removed in phases starting with the industrial consumers [40].

fitting the observed long term distribution of mean wind speeds besides its simplicity and flexibility [18,23,24]. The Weibull distribution function is initially a three parameter function expressed mathematically as [24]:

$$f(v) = \frac{k}{c}\left(\frac{v-\delta}{c}\right)^{k-1} \exp\left[-\left(\frac{v-\delta}{c}\right)^{k}\right] \quad (1)$$

where $f(v)$ is the probability density function; $v \geq 0$ is the wind speed (m/s); $k > 0$ is the shape parameter; $c > 0$ is the scale parameter (m/s) and δ is a location parameter. The location parameter is usually assumed to be equal to zero and the Weibull model used in the wind literature is a two parameter model [24] and accordingly the Weibull probability density function is expressed as [25,26]:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (2)$$

The cumulative probability function of the Weibull distribution is given as (Mathew [19]: 68, Akpinar et al. [25]: 558).

$$F(v) = \int_0^{\alpha} f(v)\,dv = 1 - \exp\left[\left(-\frac{v}{c}\right)^{k}\right] \quad (3)$$

Many methods can be found in the literature for determining k and c such as the graphical method, the standard deviation method, the maximum likelihood method, the moment method and the energy pattern factor method [19,20]. In this research the maximum likelihood technique will be employed to estimate the Weibull distribution parameters of the studied wind regime. This technique is considered to be “the most frequently used estimation technique after the least square” [27]. The maximum likelihood technique is applied in a large majority of empirical estimation and is characterized by the asymptotic properties of its estimators[5] [27,28]. A large number of studies (see for example: [24,29]) have used the method of the maximum likelihood to estimate the two Weibull parameters of the wind speed distribution function. The ML method is based on estimating those parameters that maximize the likelihood function $L(\theta|Y)$, where the necessary condition for maximizing $L(\theta|Y)$ is the likelihood equation [27]

$$\frac{\partial \ln L(\theta|Y)}{\partial\theta} = 0. \quad (4)$$

The probability density function is the Weibull distribution function which has been presented in Eq. (2), and the corresponding likelihood function is given by [29]:

$$L(c, k|v) = \prod_{i=1}^{n} kc^{-k} v_i^{k-1} \exp(-c^{-k} v_i^{k}). \quad (5)$$

Since the log likelihood function is easier to maximize, one can get first the natural logarithm of the likelihood function of n observation which yields [29]:

$$\ln L(c, k|v) = n \ln k - nk \ln c + (k-1)\sum_{i=1}^{n} \ln v_i - c^{-k}\sum_{i=1}^{n} v_i^{k} \quad (6)$$

Given that there are two parameters to be estimated, there will be two likelihood equations as following:

$$\frac{\partial \ln L(c,k)}{\partial c} = -nkc^{-1} + kc^{-1(k+1)}\sum_{i=1}^{n} v_i^{k} = 0 \quad (7)$$

$$\frac{\partial \ln L(c,k)}{\partial k} = nk^{-1} - n \ln c + \sum_{i=1}^{n} \ln v_i - c^{-k}\sum_{i=1}^{n} v^{k} \ln v_i - c^{-k} \times \ln c \sum_{i=1}^{n} {v_i}^{k} = 0 \quad (8)$$

From these two likelihood equations, the maximum likelihood estimators for the shape (K) and for the scale parameter (ς) can be determined as follows [24]:

$$\varsigma = \left[\left(\frac{1}{n}\right)\sum_{i=1}^{n} v_i^{K}\right]^{(1/K)} \quad (9)$$

$$K = \frac{n}{(1/\varsigma)\sum_{i=1}^{n} v_i^{k} \ln v_i - \sum_{i=1}^{n} \ln v_v} \quad (10)$$

Details about the applied optimization technique are provided in Section 4.

3. Wind speed data of Cairo

The wind speed data of Cairo used in this paper was measured by the meteorological station of Cairo International Airport located in Heliopolis, 22 km of Northeast of central Cairo and 40 km from the Giza Pyramids (http://www.cairo-airport.com/). At this station, wind speed is captured using an anemometer placed at 10 m above the ground level. In this research, a short term data source consisting of 12 month starting the first of January 2009 and ending the 31st of December was adopted and analyzed. The data used in the estimation are mean wind speed data – averaged over 30 min period. The total number of observations (wind speed) used in the analysis is 17,425 observations as 95 observations corresponding to different months and at different timing were not available. The average wind speed is 3.43 m/s and the standard deviation is 1.74. The maximum wind speed logged that year in Cairo was 24.67 m/s and was measured in the month of December.

4. Empirical results

4.1. Estimation of the Weibull parameters

To find the value of maximum likelihood estimators presented in Eqs. (9) and (10) and consequently reach the Weibull p.d.f. corresponding to the studied site, the calculation process used was as follows:

1) Scanning over a range of k, from 0.05 to 10 with a step size of 0.05, and calculating the value of the scale parameter at each value of the shape in the predefined range (0.05–10).
2) Calculating the likelihood function at each c and the corresponding k.
3) Selecting from the calculated ln likelihood function the function with the highest value.
4) The maximum likelihood estimators are the value of k and c yielding the highest.

This calculation process has been applied on the collected wind speed data. The estimated parameter values for the wind speed distribution of the studied site were found to be:

Shape parameter $K = 2.05$.
Scale parameter $\varsigma = 3.87$.

[5] For a full presentation of the maximum likelihood estimators properties and their mathematical proofs, refer to Greene [26]: 486–495.

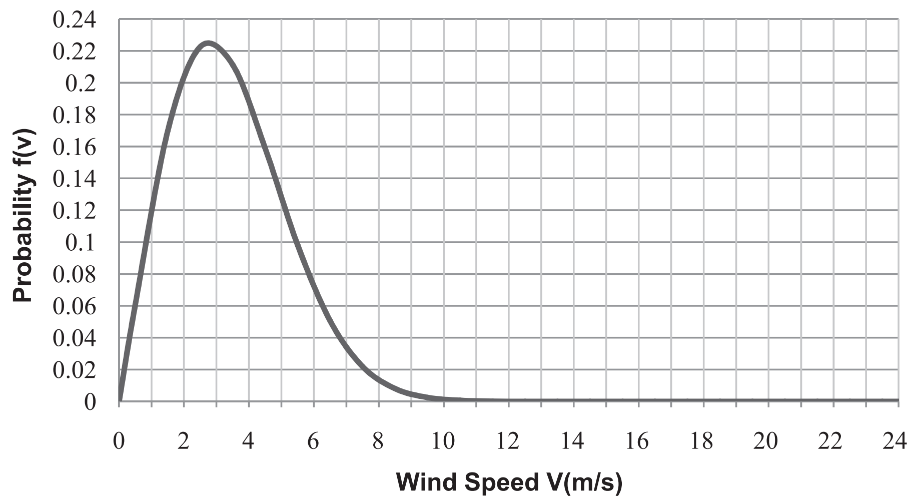


Fig. 1. The estimated Weibull p.d.f. at the wind regime of Cairo.

The estimated Weibull probability density function for the wind regime of Cairo can hence be expressed as in (11) and the corresponding Weibull cumulative function is as in (12).

$$\ldots f(v) = \left(\frac{2.05}{3.87}\right)\left(\frac{3.87}{2.05}\right)^{2.05-1} \exp\left[-\left(\frac{v}{3.87}\right)^{2.05}\right] \tag{11}$$

$$\ldots F(V) = \text{Prob} \quad (v \geq V) = 1 - \exp\left[\left(-\frac{V}{3.87}\right)^{2.05}\right] \tag{12}$$

Figs. 1 and 2 are a plot of the estimated wind speed distribution at the studied site:

This c.d.f. graph shows that 90% of the time the wind blows between 0 and 6 m/s. The studied site (Cairo) is hence characterized by being a low wind speed site and the small value of the estimated Weibull scale parameter supports this conclusion.

To test the significance of the estimated parameters the variance–covariance matrix of the maximum likelihood estimator can be used. The elements of the matrix are as shown below (Greene [27]: 493–495):

$$\text{VarCov}_{\xi-K} = \begin{bmatrix} -\dfrac{\partial^2 \ln L(\varsigma, K)}{\partial\varsigma\partial\varsigma} & -\dfrac{\partial^2 \ln L(\varsigma, K)}{\partial\varsigma\partial K} \\ -\dfrac{\partial^2 \ln L(\varsigma, K)}{\partial\varsigma\partial K} & -\dfrac{\partial^2 \ln L(\varsigma, K)}{\partial K\partial K} \end{bmatrix}^{-1} \tag{13}$$

where the diagonal elements of the matrix represent the variance of the estimators and the off diagonal elements is their covariance. From the variance, one can calculate the standard error and consequently the value of the t calculated. The result of the tests is briefed in Table 1.

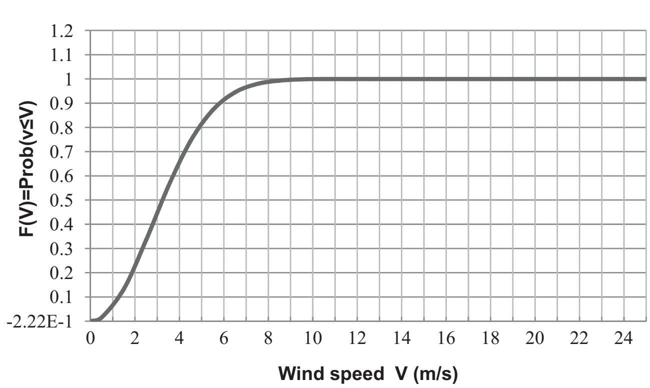


Fig. 2. The estimated Weibull c.d.f.

Accordingly, the estimated scale and shape parameter were significant at 95% confidence level one can confidently use the estimated probability density function of wind speed to calculate the potential wind electrical supply that could be generated at this site.

Furthermore, the possibility to describe the observed wind speed data using the Rayleigh wind speed distribution was tested. The Rayleigh function is a special case of Weibull where the shape parameter is equal to 2 so it has the following form [30,31]:

$$\ldots f(v) = \frac{2v}{\varsigma^2} \exp\left[\left(-\frac{v}{\varsigma}\right)^{K}\right] \tag{14}$$

For this testing purpose, the likelihood ratio test was used. The LR test statistic λ_{LR} follows for sufficiently large sample size a χ^2_R distribution with degrees of freedom equals to the number of restricted parameters [27]. Testing the hypothesis that the observed data can be modeled using a Rayleigh distribution is equivalent to use the LR test to examine the hypothesis that the shape parameter K is equal to 2 (Table 2).

The result of LR test has pointed that the observed wind speed data is not well fitted to a Rayleigh distribution and the estimated Weibull distribution should then be used to describe the collected wind regime of Cairo.

4.2. *Estimation of the wind electrical supply*

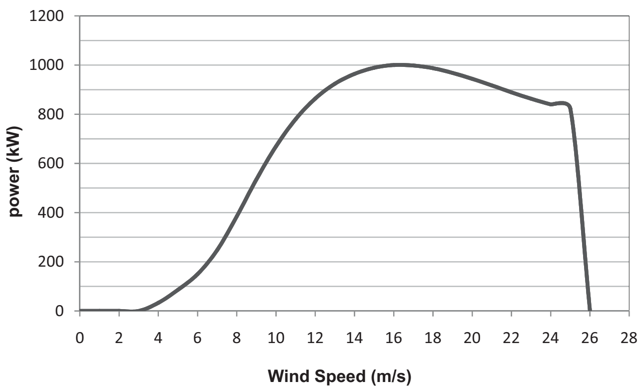
Now after testing for the significance of the parameters as well as the convenience of the Weibull distribution to the collected wind data what remains is to estimate the potential wind supply in

Table 1
Testing the significance of the estimated Weibull parameter.

Hypothesis	t calculated	Significance level	t tabulated	Conclusion
$\varsigma = 0$	58.37	0.05	1.667	Reject
$K = 0$	205	0.05	1.667	Reject

Table 2
Likelihood ratio test.

Hypothesis	λ_{LR}	Degrees of freedom	$\chi^2_{0.05}$	Conclusion
$K = 2$	13.01532	1	3.84	Reject



Source: Masters 2004: 364.

Fig. 3. Power curve for NEG Micon 60/1000.

the studied region. Estimating the electrical energy generated by a wind turbine over a specific period necessitates the availability of two tools: the wind speed probability distribution at the studied site along with the power characteristics of the turbine. With these two tools, the total energy can be calculated by summing up the energy corresponding to all possible wind speeds blowing in the site and at which the turbine can operate [22].

Now with the Weibull cumulative distribution in hand – estimated in Eq. (12) – what remains to determine is the size of the turbine that will be used in energy generation. Among the offered types in the market, the turbine 'NEG Micon60/1000' has been selected by the researcher to proceed with the energy estimation question. This turbine was selected for two reasons. First, it has specifications matching the distribution of wind regime of Cairo. Namely, a rotor diameter of 60 m which is relatively large compared to turbines with the same rated power. Additionally it is mounted on a relatively tall hub of 70 m height.[6] Such specifications are recommended to be present in turbines that will be installed in a low wind speed area [31] such as Cairo. The second reason is the availability of data about its real power curve which is needed for the purpose of energy calculation. The NEG Micon 60/1000 power specifications is visualized in Fig. 3.

To calculate the wind electrical output of this turbine if installed at the selected wind regime, an adjustment of the collected wind speed data (17,425 observations) to the height of 70 m (the hub height of the chosen turbine) was necessary as the wind speeds data were logged at a 10 m height (the anemometer height) while we are now concerned with the speed available at the rotor height. The adjustment for hub height is done using formula (15) [31]:

$$\left(\frac{v}{v_0}\right) = \frac{\ln(H/z)}{\ln(H_0/z)} \qquad (15)$$

where v is the wind speed at the hub height H (in this study it is 70 m) and v_0 represents the wind speed measured at the anemometer height H_0 which is presently 10 m and z denotes the roughness length that differs according to the type of terrain over which the wind blows. Since Cairo is a city with urban district and many windbreaks, the applied roughness length z to be used in formula (15) is equal to 0.4 [31]. With this adjustment, the scale parameter has changed from 3.87 at the 10 m height to 6.21 at 70 m height, while the shape parameter remains the same. The change in the scale parameter was expected because the scale is tightly related to the average wind speed that has increased with the higher hub to stand at 5.5 m/s. After completing the adjustment to the turbine hub height; the value of the annual energy generated in the wind regime of Cairo can be calculated by:

1) Estimating the number of hours per year at which each wind speed blows at the site using Weibull cumulative density function.
2) Combining the power delivered at each wind speed (given by the power specification of the turbine) with the number of hours per year at which each wind speed blows (estimated in step one).

Applying this calcualion method (see Appendix A), the total electrical generated by this turbine if installed in the studied wind regime was found to stand at approximately at 1.7 million kWh.

4.3. Economic evaluation of the wind project

Given this potential wind electrical supply, an economic analysis was conducted to determine whether generating electricity through wind will be an economically feasible project[7] or not from the perspective of the project developer who is an intensive energy user. More precisely, the energy user (customer) in the context of this analysis is assumed to be: an energy intensive industry, operating in or near by the studied site (Cairo) and which is connected to a medium voltage power service. The industry is receiving electricity from the local electrical company and now it is considering autoproducing part of its electricity needs through a self installment of a 1000 kW wind turbine (with specifications similar to the turbine used in the energy calculation). Given that wind project is a capital intensive long time project, the economic viability has to be determined using indicators that take into account the time value of money [32]. For this purpose, a capital budgeting framework that employs the NPV and the IRR project evaluation methods was adopted. According to Welch and Venkateswaran [33], this framework is suitable to evaluate investment in new technology such as projects in wind energy.

The following equation demonstrates how a project's NPV is calculated [34]:

$$\mathrm{NPV} = C_0 + \frac{C_1}{(1+K)} + \frac{C_2}{(1+K)^2} + \frac{C_i}{(1+K)^3} + \cdots + \frac{C_n}{(1+K)^n} \qquad (16)$$

where C_i denotes the cash flows of the project occurring in the ith year (or period) and C_0 represents the initial investment (initial outlay). The discount rate is denoted by K and n is the number of years in the future. The discount rate can represent the cost of capital or more generally the interest rate that could have been earned if the money was invested in the best alternative investment. Worth to note that in this equation all cash flows are discounted except the initial outlay as it is assumed to take place in the present. The decision rule in the NPV technique is to reject a project with a negative NPV since it means that the present value of the cash outflows exceeds the present value of the cash inflows and to accept the project if its NPV is positive [34,35]. The other investment evaluation method used is the IRR which is closely related to the concept of NPV. The concept of IRR refers to the discount rate that makes the present value of a project equals to zero. It can also be defined as the return that the project earns on the invested funds. The decision rule to accept a project when considering the IRR method is to find that the project's IRR exceeds its cost of capital and when two or more projects are compared the best project is the one with the highest IRR [31,34,36].

[6] The hub height for turbine size of 1000 kW is in the range of 40–110 m (source: http://www.thewindpower.net/).

[7] The term economically feasible will be equivalently interchanged with the term financially viable and that is because the analysis is exclusively conducted from the investor viewpoint.

Table 3
Base case assumptions.

Wind project lifetime	20 years
Wind turbine rated power	1000 kW
Hub height	70 m
Wind turbine capital cost	900 €/kW
Operations and Maintenance Cost	1.2 c€/kW
Discount rate	8%
Annual electricity generated	1,696,061 kW/h
Applied electricity price	4.445 c€/kW
Characteristics of the wind regime at hub height	Weibull distribution
Wind speed distribution	$K = 2.05$
Distribution parameter	$C = 6.21$
Average wind speed at hub height	$\bar{v} = 5.50$ m/s

Each element considered in the calculation of the NPV and the IRR are presented below.

C_0 which denotes the initial outlay is in the context of this analysis the capital cost of a wind turbine, this cost can be divided into: the cost of the turbine itself as provided by the manufacturer and some other additional cost (auxiliary cost) such as the site work that includes the foundation, the electric installation cost, the grid connection, consultancy and land rental. The total capital cost depends on the size of the turbine and also varies between countries of installation and it is estimated to vary from 900 €/kW to 1150 €/kW [37]. In this analysis, the cost of 900 €/kW will be assumed.

C_i which denotes the net cash flows occurring during the lifetime of the investment. It is the difference between cash inflows and cash outflows. *The cash outflows* represent the operation and maintenance costs of the wind turbine. The components of the O & M costs are the regular maintenance cost, repair, insurance and administration and the spare parts costs. Based on what has been experienced in a number of countries (Germany, Spain, UK and Denmark), these costs were estimated to stand at nearly 1.2–1.5 c€/kW of produced wind power [37]. In the present analysis, the rate of 1.2 c€/kW was assumed. On the other hand, *the cash inflows* in this analysis represent the savings that can be realized after installing the wind turbine. By installing a wind turbine, the user can generate electricity to power his activities and hence reduce his electric bill paid to the utility (or local electric company). The amount of money saved is based on the annual energy that can be generated and the electricity rate charged by the utility on this electricity customer. The annual energy generated has been estimated to be equal to 1.7 million kWh. The customer (the electricity user) was defined to be an energy intensive industry connected to a medium voltage power service. According to the latest tariff structure set by the Egyptian Ministry of Electricity and Energy, such category of user is subject to pay 33.4 piaster/kwh[8] besides a demand charge of 10.4 Le/kW-month[9] [5]. It must be mentioned that neither the cost of removing the turbine at the end of its lifetime nor the revenue that could be earned from selling it (its residual value) is considered in the cash flows of the last year of the turbine operation.

K denoting the discount rate used to compute the present value of the net cash flows occurring over the life time of the wind turbine (typically 20 years) is assumed in the base analysis of the NPV calculations to be 8%. The discount rate applied in similar studies – assessing the viability of wind energy projects – is usually lying within an interval of 5–10% (see for example [36,38]). A summary for the assumptions used to calculate the NPV of the wind project is provided in Table 3.

[8] When converted to euro using the exchange rate 1 euro = 7.4965, the energy rate will be 4.455 c€/kW.

[9] The demand charge is not affected by the installment of the wind turbine as it is considered a fixed cost that the user must pay to the utility regardless of electricity received.

Under these base case assumptions, the NPV of the project was calculated and it was equal to:

$$\text{NPV} = -€357,629 \tag{17}$$

The negative value of the NPV indicates that the installment of the wind turbine will be an uneconomic investment. The industrial customer will not be able to cover all of the costs of his investment in the wind energy project. Hence, auto-producing electricity from wind is not a worthwhile investment and this customer should buy all of his electricity needs from the grid as he used to do. Besides the base case, three other scenarios were assessed where some parameters used in the base case were replaced with new one to assess the impact of such changes on the project's viability.

Scenario one: Changing the discount rate

In the base case, the discount rate used to calculate the NPV was 8%. Now in this first scenario, a discount rate of 5% will be assumed while keeping all the other parameters used in the base case unchanged. The NPV corresponding to the 5% discount rate is:

$$\text{NPV} = -€211,563 \tag{18}$$

The project's NPV is still negative even at a lower discount rate therefore it still cannot be qualified as an economically viable project. The impact of reducing the discount rate on the project's NPV is illustrated in Fig. 4.

The NPV profile shown in Fig. 4 indicates that at any discount rate above the designated IRR (holding all other factors of the base case assumptions unchanged) the project is economically unfeasible. Given this low IRR, the project of installing a stand alone wind system should be rejected since any realistic assumptions about the cost of capital in the Egyptian financial market (or more generally the opportunity cost) will exceed 2%.

Scenario two: Escalating the electricity tariff

In the base case as well as in the first scenario, the electricity user was paying to the electricity company a tariff equal to 33.4 piaster/kWh. This electricity tariff was assumed to be constant over the lifetime of the project and consequently the annual monetary savings that the project can bring were also constant. In this scenario, the project's NPV will be calculated under the same parameters of the base case except that now the electricity tariff is assumed to be subject to a 5% yearly increase. The wind project's NPV was in this second scenario equal to:

$$\text{NPV} = €39,678.66 \tag{19}$$

The positive NPV means that the present value of the savings – realized with the autoproduction of electricity using the wind turbine – has exceeded the present value of all the project's costs. It can be concluded that under Scenario two the installment of the wind energy project is a worthwhile investment.

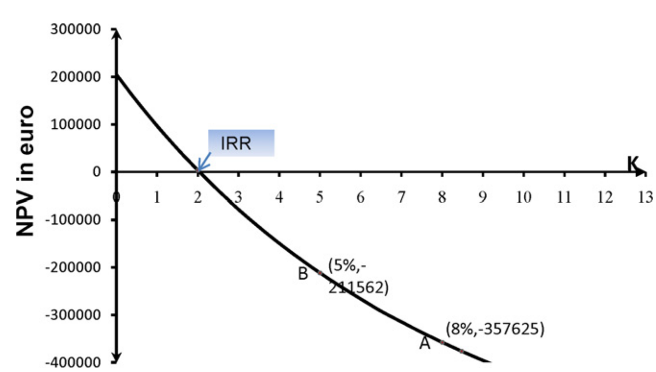


Fig. 4. Moving from the base case to Scenario one.

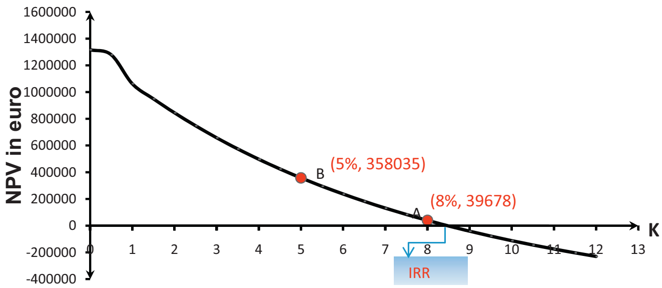


Fig. 5. Moving from Scenario two to Scenario three.

Scenario three: Combining Scenarios one and two

Under this scenario, the NPV is calculated using a 5% discount rate and assuming a 5% yearly increase in the electricity which gave the following result:

$$NPV = €358,035 \qquad (20)$$

Obviously, the NPV under this third scenario indicates that the wind project is much more attractive than in the second scenario and it has enjoys a larger margin of safety.

The impact of varying the discount rate from 8% (Scenario two) to 5% (Scenario three) on the project's NPV is illustrated in Fig. 5.

As shown in Fig. 5, when the electrcity price charged by the utility witnessed a 5% annual increase, the IRR of the wind project standed at approximately 8.5%. Worth to be mentionned that the increase in the price of electricity (generated from conventional source, i.e. fossil fuel) is usually higher than the increase witnessed in the rate of inflation (Hau [39]: 764). Accordingly the annual increase in the price of electricity can be higher then the assumed rate of 5% if the inflation rate in Egypt exceeded 5% which was in fact the case in the last 7 years since 2003 [40]. And with a higher annual rate of price increase the wind project can witness a higher NPV then the one realized and shown in Fig. 5.

Besides the positive effect a higher rate of price increase will have on the project's NPV there is also the effect of the new Electricity Law. In fact this law imposes higher electricity tariff on all industrial customers by gradually removing the subsidies on electricity starting in the first phase with the large industrial customers (over the period 2011–2014) and then followed by medium sized industries in the second phase (from 2014 to 2017) and by 2020 all customers categories should be subject to unsubsidized prices [41]. Accordingly under unsubsidized electricity price, the investment in the wind project will prove to be even more financially sound then Scenario two and three as any assumed annual rate of increase should take effect in the future on higher prices than the price used in this financial analysis (33.4 piaster/kWh) which is a subsidized price.

5. Conclusion

Egypt has currently the largest installed wind capacity in Africa and the Middle East. By 2020, the Egyptian energy sector targets to generate 12% of the electricity needs from wind making from it the major renewable energy source in the country electricity mix. So far, the wind capacity installed in Egypt was exclusively developed by the government via the new and renewable energy authority. This capacity took the form of large wind farms that supplies electricity to meet large electric demands namely that of national bulk power stations.

This paper attempted to examine the possibility of installing a wind energy project whose developer is an energy intensive user operating in Cairo and who seeks to auto-generate part of his electricity needs from the wind resources available at his location. In order to answer whether installing a wind turbine will be a worthwhile investment or not, the wind resource of this site has been assessed. The results of the econometric estimation have indicated that Cairo has low wind resources capacity. In spite of this disappointing result, the financial analysis carried over different scenarios has pointed that even with the poor wind resources of Cairo the wind project can prove to be financially viable. Prerequisites for a positive net present value of the investment are annual electricity price increases of 5% combined with a discount rate equal or below 8%. In this situation, the wind project is feasible and sustainable without any government incentives. However, if the price of the electricity charged by the utility and distributed via the national grid is expected to increase by less then 5% or if the discount rate dictated by the market is higher then 8%, then the wind project proved to be unfeasible. Accordingly, the energy user should then refrain from installing private wind turbines and continue to buy all needed electricity from the grid. In this case, the development of private investments in wind project will require public incentives such as the government provision of low interest loans or lump sum subsidies.

Table 4
Annual energy delivered at each wind speed.

Wind speed (m/s)	Power (kW)[a]	Probability	Hours/year at wind speed[b]	Energy (kW/h)
0	0	0.0057	49.92	0
1	0	0.0472	413.42	0
2	0	0.0906	793.41	0
3	0	0.1221	1069.73	0
4	33	0.1379	1208.36	39,875.77
5	86	0.1379	1208.16	103,901.55
6	150	0.1251	1095.45	164,317.29
7	248	0.1041	912.31	226,253.57
8	385	0.0803	703.13	270,703.31
9	535	0.0575	503.87	269,569.04
10	670	0.0384	336.79	225,652.5
11	780	0.0240	210.44	164,144.44
12	864	0.0141	123.11	106,367.49
13	924	0.0077	67.51	62,377.24
14	964	0.0040	34.73	33,477.79
15	989	0.0019	16.77	16,586.28
16	1000	0.0009	7.61	7606.53
17	998	0.0004	3.24	3235.02
18	987	0.0001	1.30	1281.38
19	968	0.0001	0.49	473.15
20	944	0.0000	0.00	0
21	917	0.0000	0.00	0
22	889	0.0000	0.00	0
23	863	0.0000	0.00	0
24	840	0.0000	0.00	0
25	822	0.0000	0.00	0
26	0	0.0000	0.00	0
Total electrical supply			1,696,061 kW/h	

[a] The power data is retrieved from the power specification of the NEG Micon 60/1000 that was illustrated in Fig. 3.
[b] Values are rounded to the nearest hundredth.

Appendix A.

See Table 4.

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